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COLD-FORMED STEEL: RESEARCH TO DESIGN

by Albert L. Johnson ¹

INTRODUCTION

Structural design is a process involving research, experience, and judgement. Development of written procedures for design, and acceptance of these procedures, or specifications, by code authorities, presents the structural designer with a framework within which he or she can work in the interests of efficiency, economy, and public safety.

The development of American Iron and Steel's Specification for the Design of Cold-Formed Steel Structural Members, and, in particular, the research which provides the sound basis for the validity of the Specification provisions, will be discussed in the following paragraphs. Past, present, and contemplated future investigations will be described. Although the emphasis is on research in the United States, an attempt will be made to highlight the relationships with studies in other countries.

Deciding the need for a particular research topic, development of the problem, planning the investigation, carrying out the actual study, reporting the results, and translating the results into the specification form in which they can be used directly by the structural designer, will be reviewed for a few selected topics.

Finally, an attempt will be made to put this activity on cold-formed steel structural members into perspective by reviewing the related activities of other organizations.

ORIGINS

There is a story that the prompting for the steel industry to get into research on light gage steel was the denial of the use of steel floor deck by the building department of a major city because the thickness was less than that city's minimum allowable of one-fourth inch. This sounds amazing today, since we all see thin-walled, cold-formed steel in a wide variety of forms used for load carrying purposes in many different types of structures. How did this type of structure, so common today, gain widespread acceptance?

Dr. George Winter, now Professor Emeritus of Structural Engineering at Cornell University, recalled in a paper presented in 1959 (Ref.1):

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It was only some 25 years ago that excess sheet capacity in this country called for new outlets of light gage products. From that time dates the development of cold formed steel construction, chiefly in the lighter gages from 1/8 to 1/32 in. This development has proceeded at a rapidly increasing pace during the last 10 years. Although tonnagewise only a fraction of hot rolled production, cold formed steel structural shapes, panels, decks, curtain walls, etc., today constitute a large and growing industry. As it developed, it became apparent that its products supplement and complement, rather than compete with, established hot rolled construction.

Now, 23 years later, the growth trend continues. In fact, more sheet steel goes into construction today than any other steel mill product.

Dr. Winter, in the same 1959 paper, helps provide the answer to the question posed earlier -- how did cold-formed steel achieve acceptance:

While their products were successful engineeringwise, their acceptance in building construction ran into two difficulties which were, really, two facets of the same problem. The one is the fact that the usual methods of designing hot rolled steel structures are inadequate for the design of many [thin walled] shapes . . . In consequence, many architects and engineers, faced with structural shapes whose performance they could not calculate, refused to incorporate them in their designs. The other, and more decisive one, was that the various building codes, municipal and governmental, made no provision for light gage steel construction. This was a serious obstacle since any type of construction not recognized in a building code can be utilized in the particular locality only on the basis of special dispensation, which is costly, time consuming and often difficult to obtain.

In this predicament, American Iron and Steel Institute . . . constituted a technical subcommittee, in 1938, with the assignment of developing a specification for the design of light gage steel structures. The subcommittee soon realized that the factual background and research information which is needed for the formulation of design methods, simply did not exist. To provide this information, a contract was concluded, early in 1939, between the Institute and Cornell University under which the latter was to undertake the necessary research on the performance of thin walled, cold formed steel structural members and present the results in a manner suitable for the formulation of design specifications. The writer had the good fortune of being appointed as investigator on this project, and was put in charge of it a year or so later. He has been at it ever since.

And he's still at it 43 years later, and the good fortune seems to be that of the thousands of engineers and architects who directly use the results of the investigations which started in 1939, the steel producers, the manufacturers, and the consumers who benefit from use of a safe and economical structure.

Of course, the identification of the need, the definition of the character of the problem, and the initiation of the research investigation were only part of the package. American Iron and Steel Institute published the first edition, Specification for the Design of Light Gage Steel Structural Members, in 1946. With rapid adoption by most building codes in the country, the constraints and inhibitions to design, manufacture, and construct with thin walled steel largely disappeared.

This process has been continuous, with increasingly sophisticated demands by manufacturers, growing awareness among designers, availability of new steels, and development of modern construction techniques all providing impetus. The current edition, Specification for the Design of Cold-Formed Steel Structural Members (Ref.2), published September 3, 1980, was preceded by four intervening editions after 1946, each made possible by well planned and executed research investigations in conjunction with experience acquired by the structural design profession.

RESEARCH: 1939-1961

The first two decades of AISI sponsored research on cold-formed steel structural member behavior were concentrated, quite logically, on the response of beams, studs, roof decks, and connections to applied loads.

It happens that the AISI work was not the only research effort of Dr. Winter at Cornell on thin-walled members in those early days. A study (Ref. 3) of the phenomenon of shear lag in wide, thin flanges constituted the focus of Dr. Winter's PhD thesis research. It also provided directly the basis of the Section 2.3.5 of the Cold-Formed Specification on unusually short spans supporting concentrated loads, which gives the maximum allowable ratios of effective design widths to actual widths for tension and compression. The 1946 Specification called for attention to tension only, while later editions added the same requirement for compression. Nevertheless, this early research has stood the test of time, and appears in the Specification today.

It was perhaps more than a fortuitous circumstance that prompted the steel industry to assign Cornell University the task of the systematic studies which lead to the background for the Cold-Formed Specification, and, in fact, included drafting the actual wording which appeared in the Specification. This involvement of the researcher in the preparation of the design provision, i.e., the translation of research into practical engineering application, continues today as one of the important aspects of goal-oriented research. Without the investigators' involvement in developing the phrasing and equations of use to the designer, the task would be difficult indeed.

The earliest beam research explored the distribution of stresses in tension and compression flanges, compression flange stability, lateral stability, and beam deflections. The phenomenon of post-buckling strength, and the concept of effective width were introduced fairly early in the game. Continuing investigations were concerned with bracing requirements, web crippling, the distinction between stiffened and unstiffened elements, further refinement of the understanding of thin-walled beam behavior, and studies of the behavior of several of the basic cross-sectional shapes possible in

cold-formed steel. Throughout all of the research, attention was given to the need to put the final results in a form which the design engineer could use in a codified presentation. In retrospect, the approach to the problem, the methodology of investigation, and the thoroughness of the verification by testing provide a model for any investigator.

A similar, but less extensive investigation was made into the behavior of compression members. The concentration was on wall studs, and the interaction of studs and sheathing material in a structural subsystem. Bracing requirements were established, and a test method developed for determining bracing values of sheathing. Some work was done on the interaction of local and overall buckling of compression members, as well as on the combination of bending and axial loads.

Roof decks were tested extensively. This application for cold-formed sheet steel in structures was one of the more significant at that time, and remains so today. The basic principles established apply to floor deck and to wall panels, and are consistent with the methods of flexural member design which have been established.

Bolted connections were the main emphasis in the studies of joining methods for cold-formed steel conducted in the 1950's. Provisions for bolt use were introduced in the 1956 Edition, with high-strength bolts added in 1962. A few tests were made of fusion welded connections, but systematic studies of fusion welding in cold-formed steel did not begin until the mid 1960's.

The research described briefly above is, for the most part, well documented in published papers. The Commentary on AISI's Specification (Ref. 4) contains a record of the research background and the reasoning leading to the provisions of the Specification. Those interested in historical aspects are advised to refer to Winter's 1968 Commentary (Ref. 5), since the current Commentary format has been changed to a section-by-section correspondence with the Specification rather than Winter's narrative approach. All editions of the Commentary contain complete lists of references to published research documentation.

RESEARCH: 1962-1966

The early and mid 1960's saw an expansion of research topics into new areas: effects of cold-forming, fusion welding, shear diaphragms, bracing of beams and columns with diaphragms, folded plates, hyperbolic paraboloids, torsional-flexural buckling, and cold-formed stainless steel members. This listing presents an opportunity to comment on several outlets for research results besides the Cold-Formed Specification, as well as the continuing improvement and expansion of the Specification.

Reports of failures in Europe caused by buckling in the torsional-flexural mode led to initiation of a major project to develop design rules which would aid the structural designer in proportioning members whose geometry and loading would otherwise permit failures in a torsional-flexural

mode or a combination of compressive and torsional-flexural buckling. The results of this project appeared in the 1968 Edition of the Specification, and provide the structural designer with closed-form design procedures of dealing with this question for some of the more elementary loading conditions. However, some problems resulted, and some situations remain without solution except by test. The major difficulty with the design formulations is that they are, to put it simply, difficult. Just writing the provisions for the cases which were covered occupies several pages of the Specification; the design aids and explanation of those aids occupies many more pages of AISI's Cold-Formed Steel Design Manual (Ref. 6).

Although computer programs which handle the torsional-flexural equations readily are available, there remains a need for design provisions which can be handled by the designer who does not have access to main-frame computers for which programs were written or who has only occasional call to design such members. Equally important is the understanding and acceptance of designs by the building code official or plan reviewer. This subject will be expanded on below in a review of current research and a discussion of needed research.

The strengthening effect of cold-work during the forming process was the subject of a research investigation which was as extensive as that on torsional-flexural buckling, but resulted in Specification provisions which are simple and straightforward in comparison. Use in design can be particularly advantageous for the manufacturer who wishes to take this additional strength into account, thereby offering a more economical means of filling the structural function.

Arc welding was included in the Specification for many years with the same design values as used for the greater thicknesses commonly encountered in hot-rolled structural steel. The study of arc welding which was initiated in the mid 1960's eventually resulted in a completely new set of design provisions appropriate for arc welding thinner steels to other thin steels or to supporting structural steel members. However, the design provisions which appeared for the first time in the September 3, 1980 Specification would not have been possible without the parallel development by American Welding Society of the rules for welding procedures, welder qualification, and weld inspection (Ref. 7).

The use of light gage steel sheathing for its in-plane shear strength and stiffness was studied with a view toward development of a test procedure to determine strength and stiffness characteristics, and preparation of design procedures using the experimentally determined values. The results were published by AISI in 1967 (Ref. 8). Since that time, there has been a great deal of attention given to diaphragm action, including in particular the work done by the Steel Deck Institute in the United States, and that done by Bryan and his colleagues in the United Kingdom. Subcommittee 13 of AISI's Cold-Formed Advisory Group is now completing a state-of-the-art on steel diaphragms in an attempt to provide the basis for a unification of design philosophy and procedure.

The use of stainless steel in buildings for architectural purposes and for its durability led to a study of the structural performance of several of the types of stainless steel so used. The goal was to develop a design

specification paralleling that already in existence for carbon and low alloy steels. The resulting document is now in its second edition (Ref. 9). There has been some recent discussion regarding the feasibility and desirability of merging the stainless and the carbon and low alloy specifications into a single document because of the commonality of many aspects of the design approaches.

RESEARCH: 1967-1982

The 1968 Edition of the Cold-Formed Specification saw adoption of the results of much of the research which was initiated in the expansion of the early to mid 1960's. With increasing research on topics of greater complexity the interrelationships of the Specification provisions slowed the rapid translation of results into the form readily useable by the designer. Nevertheless, there were significant advances reflected in the September 3, 1980 Edition of the Specification which warrant summarizing here. (See Reference 10 for further information.)

Professor Wei-Wen Yu and the University of Missouri-Rolla emerged as a center with particular strength in cold-formed steel research and education. Investigations of the applicability of the Specification provisions to thicker sheets and plates, the behavior of bolted connections, and the design of webs of flexural members produced results under Dr. Yu's direction which found their way into the Specification.

Cornell research on the significance of ductility, particularly on connections, permitted the introduction of provisions giving the minimum elongations and ratio of ultimate-to-yield for satisfactory performance. This research was prompted by the growing use of higher strength steels with lower ductilities and tensile-to-yield ratios. A fringe benefit of the study was the introduction of special provisions for full-hard steels with low tensile-to-yield ratios and no specified minimum elongation, a condition which had been overlooked and for which the literal use of the Specification and the practice of the industry were not in agreement.

1980 also saw introduction of a new provision which permits, in certain cases, utilization of some inelastic rotation capacity to permit higher allowable loads, a revision of the design procedures for wall studs, and expansion and clarification of the provisions for design of channel-and Z-section beams. Professor Teoman B. Pekoz, who had become a principal investigator at Cornell, was responsible for much of the research information underlying the topics mentioned in this paragraph.

Mention of two specific universities and their leading researchers should not be understood to mean that there are no other contributors. An impressive listing of ongoing research has been assembled by American Society of Civil Engineers' Committee on Cold-formed Members (Ref. 11). The 70 projects and the 69 investigators indexed represent work underway in Japan, England, Scotland, Sweden, Norway, Netherlands, Belgium, France, Romania, Canada, and the United States. The ASCE Committee is now in the process of preparing an update to this valuable document.

All of the sponsored research would be of no avail if there were not active participants on specification writing groups, such as AISI's Advisory Group, with uncounted hours given for the difficult task of putting the research results into the language and format needed by the structural designer and for the building code.

In addition, there is noteworthy research carried out in proprietary laboratories, the results of which are often provided to the groups charged with developing specification provisions.

Other research investigations carried out during this period are awaiting adoption into the Cold-Formed Specification or other published design documents. Included here are projects on perforated elements, shear behavior of steel stud wall panels, and test procedures for stub columns, columns, beams, and mechanical fastened joints.

Yet other studies are in themselves complete, but need to be integrated into the Specification with evidence derived from further exploration involving laboratory verification. These studies include behavior of members subject to combined local and overall buckling, stiffeners for compression elements, unstiffened compression element behavior, the interaction of web and flange elements in a cross-section, and basic column behavior.

Current ongoing research investigations include load and resistance factor design procedures paralleling those developed for American Institute of Steel Construction's Specification for the Design, Fabrication and Erection of Structural Steel for Buildings; the behavior and appropriate design guidance of channel- and Z-sections loaded in the plane of the web (e.g., purlins in pre-engineered steel buildings); and combined bending and axial loads in columns. The latter project includes simplification of existing design provisions for torsional-flexural buckling as one of its goals.

FUTURE RESEARCH NEEDS

In May 1982, AISI's Cold-Formed Advisory Group established a rank order for proposed areas and topics for Specification revision. Review of 54 items resulted in a basis for concentrating research and specification development efforts. The ranking, in descending order of priority, was:

- Simplification
- Channel- and Z-sections
- Stiffeners (compression flange)
- Safety factor for confirmatory tests
- Interaction of elements
- Web bending-crippling interaction for deck
- Load and resistance factor design
- Combined axial and bending load (Section 3.7)
- Unstiffened compression elements
- Columns
- Web effective width approach
- R/t, w/t, L/r, etc. limits
- Perforated elements

Screw fasteners
 Warning on use of safety factors
 Laterally unsupported compression flanges
 Combined axial and bending (Section 5.1)
 Moment redistribution
 Inelastic reserve of multiple-stiffened elements
 Uplift on arc-spot welds
 Test procedures
 Shear walls
 Definition of C_b for flexural members
 Uplift on screw or bolt washers
 Angles in bending
 Resistance welds, high-strength, low alloy
 Proof testing for completed structures and for production verification
 Composite design of floors (e.g., steel and plywood)
 Decision tables
 Seismic, cycling loads, dynamic response
 Spacing of connectors in relation to deflection prediction
 Tolerances
 Weld preheat requirements
 Shear lag and curling in wide tension flange
 Influence of cold-work
 Composite walls (e.g., steel studs and metal lath)
 Allowable bolt bearing stress for one or no washer when $F_u/F_y < 1.15$
 Corrugated sheet design
 Computer programs
 Small scale stud-sheathing shear strength and stiffness tests
 Oversize, slotted, and staggered bolt holes
 Bolt installation
 Metrication
 Sheet bending formula
 Sandwich panels
 Cross-reference other standards (e.g., composite)
 Temperature effects
 Redefine web depth
 Higher strength steels
 Fatigue
 Redefine extreme fiber
 Cylindrical tubular members
 Increase allowable for construction loads?
 Stainless.

On a scale of 1 to 6, the listing above ranges from a high priority of 2.1 for simplification down to a low of 4.5 for stainless.

This listing includes a wide range of topics. Some will require serious laboratory investigation; for some there are studies recently completed or currently underway; others are a matter for the judgement of the Advisory Group.

The question of simplification has been assigned to a new subcommittee of the Advisory Group on the Specification. The subcommittee has outlined the tasks as follows: 1) rearrange the Specification to improve clarity and

follow a more logical arrangement, 2) simplify the format and equations without loss of accuracy, and 3) develop conservative simplifications. In his keynote address at the first speciality conference in 1971, Professor George Winter stated (Ref. 12):

One of the [larger issues] is the problem of the increasing complexity of design specifications. This increasing complexity is an inevitable consequence of more refined and economical ways of using material structurally, of utilizing the full benefits of higher strength material, and maximizing the effects of our more sophisticated knowledge of structural mechanics and materials science. It is very odd that there should be a problem in this increased complexity at the very time when ever more efficient computer methods enable one routinely to carry out calculations of previously undreamed of length and complication. . . .

Yet, if computer methods could be directly specified in design codes, not only would much of the present apparent complexity disappear, but the need for many of the present approximations, most of them on the uneconomical side, would also cease. . . .

Something must be done about this or else the complexity of specifications will get out of hand while at the same time the opportunities of computerization will remain unexploited.

Eleven years later the challenge, unfortunately, remains almost unchanged.

EUROPE AND CANADA

Professor E. R. Bryan of the University of Salford described the activities of Committee T7 of the European Convention for Constructional Steelwork in a paper delivered at the Fifth International Speciality Conference in 1980 (Ref. 13). Committee T7 is charged with development of European recommendations for cold-formed steel sheeting and sections and related activities in design and construction. The membership includes representatives of ten European countries, consulting experts, and an associate member from the United States. It is fortunate that the associate is Professor Teoman B. Pekoz, one of the individuals active in cold-formed steel research and consulting and a member of AISI's Cold-Formed Advisory Group. Dr. Pekoz offers a transfer of technical information between the two groups, and, of particular advantage in the context of this paper, can through his participation in ECCS, identify European research of special interest to the AISI Advisory Group and to other researchers in the United States. He also provides the same convenience for the members of ECCS T7.

A paper edited by Professor Pekoz (Ref. 14), authored by engineers from six countries, comments on the close relationships between manufacturers and universities in conducting proprietary research, a situation which does not normally exist in this subject area in the United States.

The Canadian counterpart of AISI's Cold-Formed Steel Specification is written by the Technical Committee on Cold Formed Steel Structural Members of

the Canadian Standards Association. Close liaison between the Canadian and United States activities is maintained through cross-memberships, involvement of Canadian steel mills in research sponsored by the Canadian Steel Construction Council, and technical communications through AISI committee activities. Also, AISI's Advisory Group hosted the members of the CSA Technical Committee at a meeting in May 1982, where there was a valuable interchange of information and attitudes on the significance of current research and design trends.

OTHER ORGANIZATIONS

There are many other groups which are concerned with cold-formed steel research and design, including professional societies, research councils, and trade associations. Many of the individuals on AISI's Cold-Formed Advisory Group are active in one or more of these other groups, which include:

- American Institute of Steel Construction
- American Society for Testing and Materials
- American Society of Civil Engineers
- American Welding Society
- Canadian Sheet Steel Building Institute
- Construction Specifications Institute
- International Association for Bridge and Structural Engineering
- Metal Building Component Manufacturers Association
- Metal Building Manufacturers Association
- Metal Lath/Steel Framing Institute
- Rack Manufacturers Institute
- Research Council on Structural Connections
- Steel Deck Institute
- Structural Stability Research Council

The informal communications thus established are an important aspect of maintaining an understanding of the needs of other groups, and an awareness of activities of mutual interest.

EDUCATION

The task of research, preparation of design specifications, and gaining acceptance by building code authorities is not complete without educational activities to keep the designer up to date and to provide the basis of understanding needed by those engineers entering the field of cold-formed steel.

Professor Wei-Wen Yu deserves the credit for getting things started in a formal manner by organizing at West Virginia University the first short course on cold-formed steel. He even wrote the bulletin of notes for that first presentation which was held in 1965. Since that time, Dr. Yu and others have offered many short courses around the country, providing the educational support which is so important.

Publication of the first textbook (Ref. 15) devoted exclusively to cold-formed steel was, not surprisingly, also the result of Dr. Yu's efforts. He is now busy preparing the manuscript for the second edition.

ASCE's Committee on Cold-Formed Members is concerned about the results of a survey summarized by Dr. Paul Seaburg (Ref. 16) which revealed the low number of classroom hours devoted to teaching cold-formed steel, and in a relatively small number of colleges at that. It will indeed be a worthwhile extension of that Committee's activities if some assistance can be offered in developing curricula and encouraging their use.

The proceedings of the international speciality conferences on cold-formed steel, developed by the University of Missouri-Rolla by Professor Yu and his colleagues, offer another educational resource which extends the benefits derived from participation in the conferences themselves.

CONCLUSIONS

Review of the development of design techniques for cold-formed steel structural members, and recognition of essential ingredients -- a group of individuals with the experience and judgement necessary to plan and utilize the results of research -- has special value in today's economic climate. There is a large body of information which needs development, and there are many areas which require investigation. Time and research funds are both scarce commodities, and our best collective wisdom must be applied to select the paths which will permit continuation of past successes.

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